Effect of a femoral arteriovenous fistula on lower extremity venous hemodynamics after femorocaval reconstruction

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Purpose: To study the hemodynamic effects of an arteriovenous fistula (AVF) used as an adjunct to venous reconstructions and to determine the optimal size for such a fistula.
Methods: A model of limb circulation with an AVF (in vitro system) was constructed with silicon elastic tubes and 40% glycerin solution as the fluid medium. Pulsatile arterial flow and venous return was maintained with a roller pump and a centrifugal assist device. Flows and pressures were measured for three different fistula diameters (3, 4, and 5 mm). A canine model of venous hypertension with outflow obstruction was constructed in 15 adult mongrel dogs. After 7 to 13 days an externally supported 8-mm expanded polytetrafluoroethylene femorocaval graft was implanted with a distal AVF (3 mm, n = 5; 4 mm, n = 5; 5 mm, n = 5). Arterial and venous flows and venous pressures were measured proximal and distal to the fistula before and after exercise.
Results: In the in vitro system, flows through the venous graft increased with increasing fistula size, but venous return decreased progressively, increasing the distal venous pressure. In the canine model, flow in the venous graft increased with each AVF ($p < 0.01$). Only the 3-mm AVF resulted in decreased distal femoral vein pressure ($p < 0.01$), orthograde flow, and improved venous return with exercise.
Conclusion: AVFs increased flow through the femorocaval grafts, yet they impeded venous return. The ideal AVF-to-graft ratio used in our study was 0.375, because it increased graft flow, permitted forward flow in the femoral vein while reducing pressure, and improved venous return with exercise. (J Vasc Surg 1996;24:793-9.)

Venous thrombectomy performed for iliofemoral venous thrombosis or bypass procedures performed for venous occlusion are surgical options that are used to treat patients for acute or chronic venous occlusive disease. Patency rates after venous reconstructions, however, have been found to be inferior to those obtained after arterial reconstructions.[1-7] An arteriovenous fistula (AVF) placed distal to venous reconstructions in an attempt to improve patency was first suggested by Kunlin et al. in 1953, and it has been used with success in several series published in the literature.[3-5,8-14] Our clinical experience with prosthetic femorocaval grafts (FCGs) implanted with a femoral AVF has also been reported.[5,15,16] Venous hypertension, however, is observed in some patients after placement of a distal AVF, and at present the optimal size and location of the fistula is controversial.[17-19]

The goal of our experiments was to evaluate the acute hemodynamic changes that occur after placement of an AVF. An in vitro model of normal limb circulation and a canine model of venous hypertension, treated with FCGs, were used.

METHODS

In vitro model. An in vitro model limb circulation with an AVF was constructed with 8-mm silicon elastic tubing (Fig. 1). A 40% glycerin solution was used as the fluid medium.[20] Pulsatile arterial flow was maintained with a roller pump, and venous return was sustained with a centrifugal assist device. Mean arterial pressure in the model was maintained at 68 to 70 mm Hg, and the venous pressure when the AVF was clamped was maintained at 8 to 10 mm Hg. Venous

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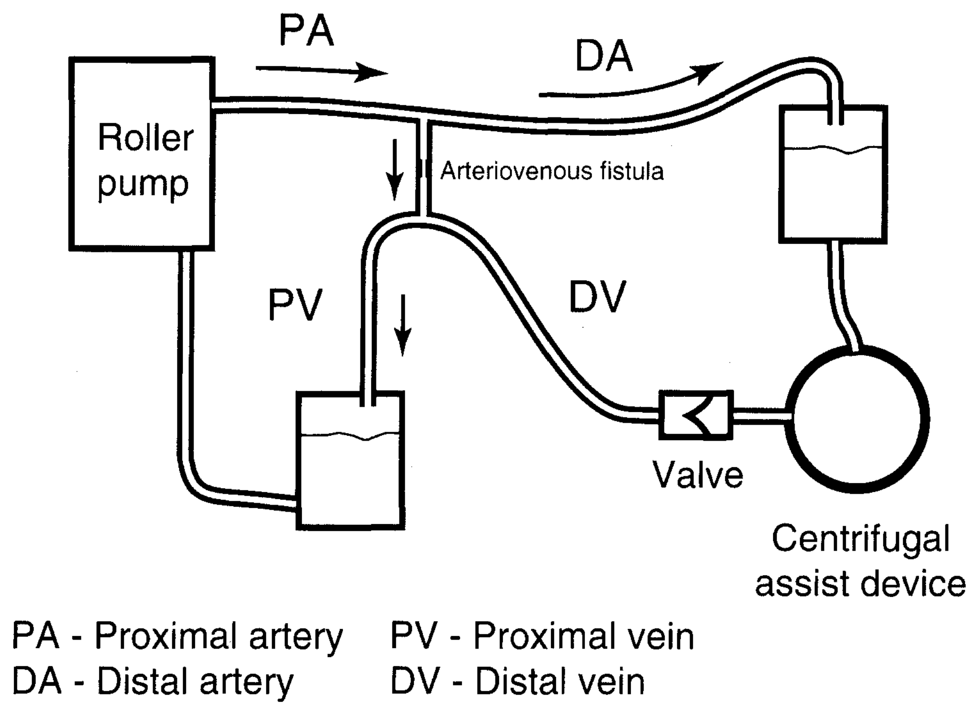

Fig. 1. In vitro model of limb circulation with AVF.

flow and pressures were measured for three different fistula diameters (3, 4, and 5 mm). A valve in the distal venous segment prevented reversal of flow. Each measurement was repeated 10 times, and mean values ± SEM were used.

Canine model. A model of chronic venous hypertension was created, modified from the method described by Lalka et al.,[21] in 15 male mongrel dogs, each weighing 20 to 25 pounds. The femoral vein was ligated at the inguinal ligament. All tributaries of the femoral vein were also ligated for a length of 5 cm from the inguinal ligament (Fig. 2). All dogs received 325 mg of aspirin 2 days before the ligation and every day until completion of the study. After 7 to 13 days, flow and pressure measurements were obtained to confirm venous hypertension. At this time, an 8-mm externally supported expanded polytetrafluoroethylene (ePTFE) FCG was implanted. A femoral AVF using an ePTFE graft of 3 mm, 4 mm, or 5 mm in diameter was also performed, at 1 to 2 cm distal to the anastomosis (Fig. 3), and the hemodynamic measurements were obtained. The fistula was placed at 90 degrees to the long axis of the vessels. The animals received intravenous gentamicin 80 mg, intravenous cefazolin sodium 1 gm, and intramuscular penicillin G benzathine 1.2 million units before bypass surgery. Intravenous pentobarbital was used for general anesthesia.

The dogs were randomly assigned to one of three groups. Group 1 (five dogs) had a 3-mm fistula, group 2 (five dogs) had a 4-mm fistula, and group 3 (five dogs) had a 5-mm fistula. The fistula-to-graft diameter ratios were 0.375, 0.5, and 0.625 for groups 1, 2 and 3, respectively. Arterial and venous flows and venous pressures were measured proximal and distal to the fistula. Exercise was simulated by electrical stimulation to tetany of the leg musculature for 20 seconds. After stimulation an immediate flow and pressure reading was taken. Subsequently, 10 more similar readings were taken 30 seconds apart, and the dogs were allowed to recover. All flow readings were taken using an ultrasound flow probe flowmeter from Transonic Systems, Inc. Two weeks from the bypass surgery, the groin was reexplored to examine for patency and to obtain the flow and pressure measurements.

Data analysis was performed with Student's paired t test when comparing within a group and with the unpaired t test when comparisons were performed between groups. Significance was defined as a p value less than 0.05. The SEM was calculated for a 95% confidence interval.

RESULTS

In vitro model. The flow pattern and pressure in the system were dependent on the size of the AVF. Flow through the proximal vein increased with increasing fistula size, whereas the inflow from the distal

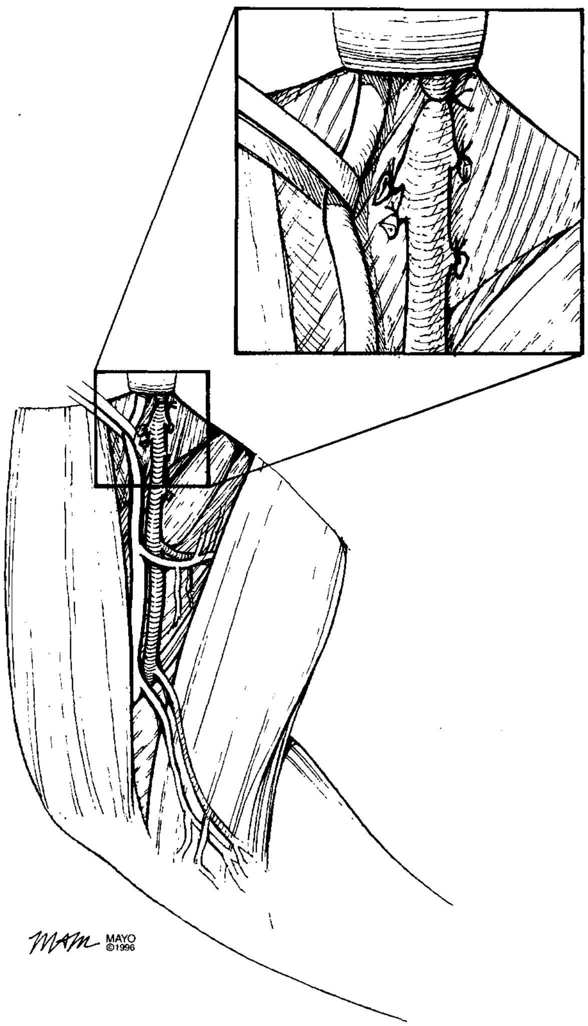

Fig. 2. Model of venous outflow obstruction in hind limb of dog with ligation of femoral vein and profunda femoris.

vein decreased (Table I). The pressure in the distal vein increased with fistula size (Fig. 4 and Table I). The 5-mm fistula resulted in no inflow from the distal vein. A valve prevented reversal of flow in the in vitro system.

Canine model. After ligation of the femoral vein and its tributaries, there was an acute rise in the femoral vein pressure, from a mean of 8.2 mm Hg (range, 7 to 11 mm Hg) to 91 mm Hg (range, 50 to 123 mm Hg). One to two weeks later, at the time of the femorocaval venous bypass procedure, the femoral vein pressure had decreased to a mean of 31.5 mm Hg (range, 21 to 39 mm Hg), but remained higher than baseline ($p < 0.01$). To confirm venous occlusion, the flow in the femoral vein was measured before reconstruction and was found to be zero in all dogs.

Mean changes in pressure with placement of a FCG and an AVF are shown in Table II. The fistula-to-graft ratio of 0.375 (group 1) resulted in a significant decrease in the pressure in the femoral vein ($p < 0.02$), whereas the larger ratios resulted in no significant decrease in the pressure and even increased the distal femoral pressures in several dogs (Fig. 5).

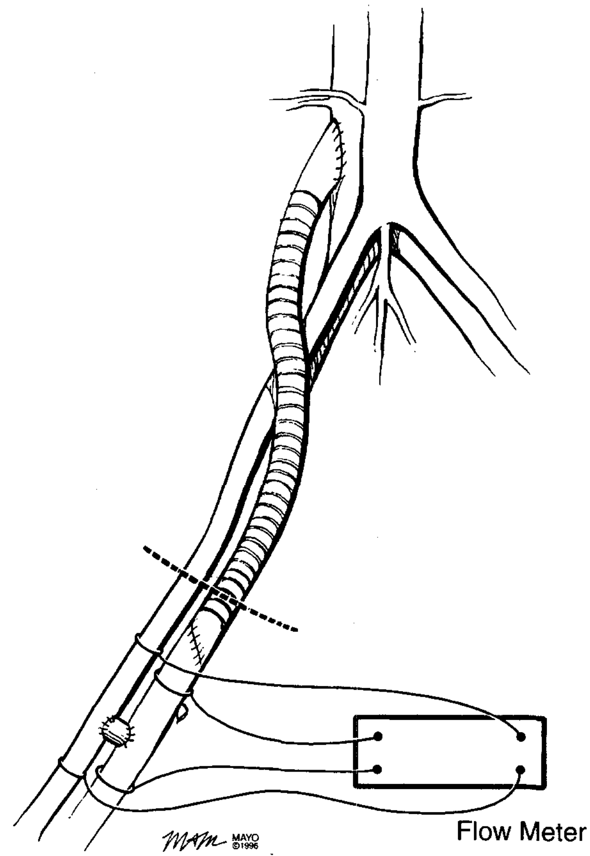

Fig. 3. Femorocaval bypass graft with femoral AVF. Flow probes were placed as shown.

All AVFs resulted in increased flow through the FCG (Table III). The flow was greatest with a 5-mm fistula and less with smaller fistulas. An AVF increased flow in the proximal artery and decreased flow in the distal artery in all cases. The flow in the femoral vein was orthograde in four of five dogs with a 3-mm fistula, but was reversed in all dogs with 4-mm or 5-mm fistulas (Fig. 6).

In the period after electrical stimulation, marked increase in venous outflow was measured from the distal femoral vein for a 3-mm fistula from 7 ml/min to 67 ml/min ($p < 0.05$; Table III). The flow increased in the distal artery yet decreased in the proximal artery, which is consistent with decreased flow through the AVF during exercise. The increased venous outflow from the distal femoral vein did not return completely to baseline during the 5 minutes

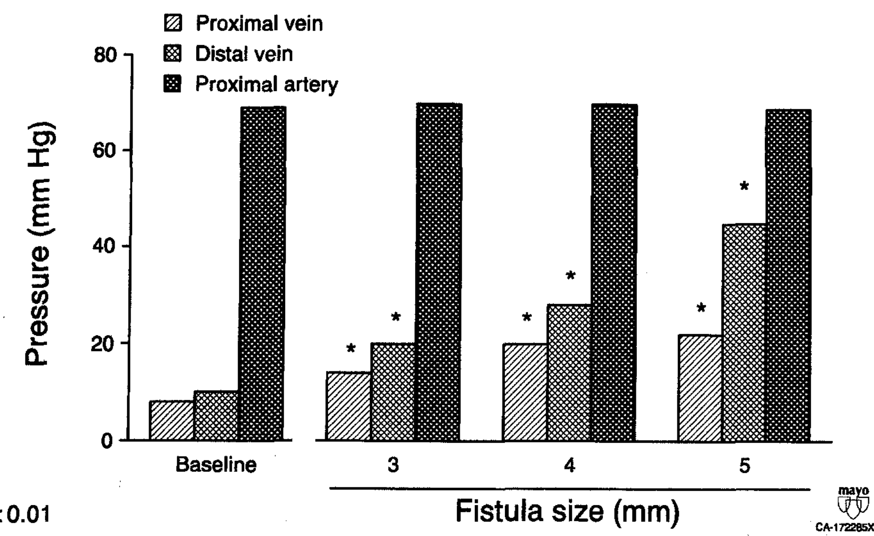

Fig. 4. In vitro model. Change in mean venous pressure after insertion of AVF. SEM is less than 0.7 for proximal artery pressure and less than 0.25 for proximal and distal venous pressure values.

Table I. Hemodynamics of the in vitro system

Fistula (mm)	*Flow from distal vein (±SEM) (ml/min)*	*Distal venous pressure (±SEM) (mm Hg)*	*Proximal venous pressure (±SEM) (mm Hg)*
none (baseline)	980 ± 3	10 ± 0.7	—
3	590 ± 2*	20 ± 0*	14 ± 0
4	230 ± 2*	28 ± 0*	20 ± 0
5	0 ± 0*	45 ± 0*	22 ± 0

*$p < 0.01$.

Table II. Femoral venous pressure before and after femorocaval bypass with AVF and after exercise

Fistula (mm)	*Preoperative (±SEM) (mm Hg)*	*Postoperative (±SEM) (mm Hg)*	*Immediately after exercise (±SEM) (mm Hg)*	*5 minutes after recovery (±SEM) (mm Hg)*
3	33 ± 4.7	15.6 ± 2.1*	16.8 ± 1.6†	15 ± 2.8†
4	30 ± 5.0	30.4 ± 8.9†	25.2 ± 6.4†	30.8 ± 6.9†
5	32 ± 4.0	43.6 ± 20.8†	42.2 ± 18.4†	41.6 ± 22.8†

*$p < 0.02$.
†Not significant.

while measurements were done. Pressure changes in the femoral vein immediately after exercise were not significant in any of the groups (Table II).

On reexploration at 2 weeks, only three grafts were patent, two with 5-mm fistulas (group 3) and one with a 4-mm fistula (group 2). Eight AVFs were patent at 2 weeks, four in group 3 and two each in groups 1 and 2. The flow readings in the patent grafts were negligible (mean, 10 ml/min). All three patent grafts were filled with large amount of thrombus.

DISCUSSION

An AVF results in a preferential low-resistance path for blood flow from the arterial to the venous system. The hemodynamic changes brought about by the fistula are mainly dependent on the diameter of the fistula. Even a small fistula results in increased flow in the proximal artery, and the proximal vein and flow in the distal artery is usually decreased. Flow in the distal vein may be orthograde or retrograde. A competent valve can prevent retrograde flow in the distal vein, but increased pressure with time may result in annular dilatation, valvular incompetence, and retrograde flow.[22] Retrograde flow can also be prevented if resistance through the proximal vein or FCG is low and is able to accommodate the increased flow caused by the fistula. So when designing an AVF, it is important to consider fistula size and changes in

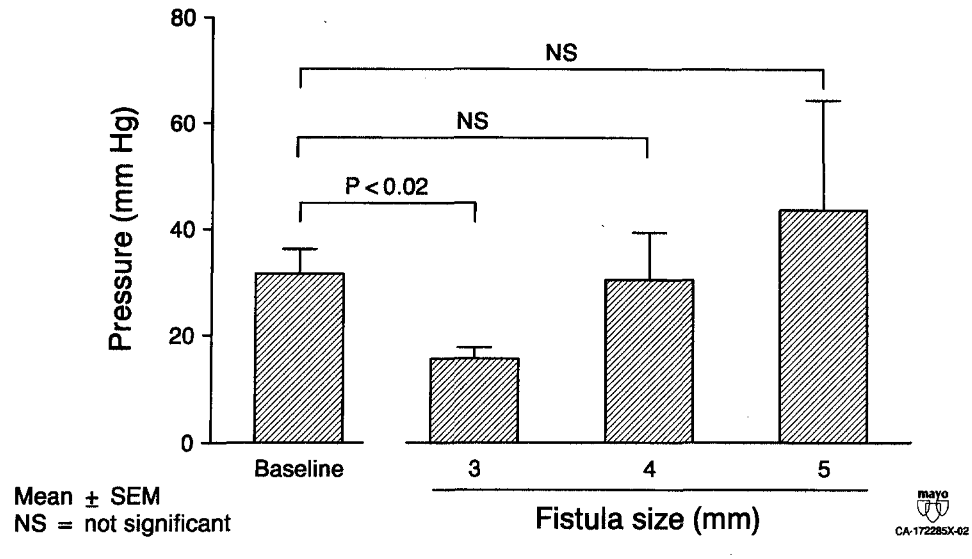

Fig. 5. Canine model. Distal femoral venous pressure after femorocaval bypass procedure and AVF.

Table III. Flow rate after femorocaval bypass and AVF, before and after electrical stimulation (exercise)

Fistula (mm)	*Inflow artery (±SEM) (ml/min)*		*Outflow artery (±SEM) (ml/min)*		*Femoral vein (±SEM) (ml/min)*		*Femorocaval graft (±SEM) (ml/min)*	
clamped	*132 ± 17*		*147 ± 16*		*68.8 ± 16*		*85.2 ± 14*	
	Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
3	495 ± 57*	397 ± 114†	99 ± 21*	140 ± 33†	7 ± 28*	67 ± 80§	242 ± 88*	254 ± 107*
4	533 ± 51*	373 ± 89†	89 ± 20*	97 ± 40†	−93 ± 21*‡	−71 ± 54†‡	224 ± 62*	157 ± 72*
5	754 ± 133*	669 ± 325†	71 ± 33*	80 ± 46†	−136 ± 46*‡	−133 ± 103†‡	399 ± 112*	351 ± 237*

*$p < 0.01$.
†Not significant.
‡Reversed flow.
§$p < 0.05$.

arterial, and, more importantly, venous hemodynamics.

The use of an AVF was first suggested by Kunlin et al.[8] in 1953 to assist the patency of a venous graft. Bryant et al.,[23] in an experimental study, first used AVFs to maintain the patency of prosthetic grafts placed in the venous system. Experimental studies in our laboratories[24-26] and in others,[17,18] and clinical studies[1-7,9-17] have reported on the use of AVF as an adjunct to improve the patency of venous grafts.

Whereas previous experimental studies have focused on the utility of AVF to maintain patency, our study investigated acute hemodynamic alterations using ePTFE prostheses of different sizes for AVF in a model of venous hypertension. The fistula was placed at 90 degrees to the long axis of the artery and vein to minimize its length, which allowed for minimal resistance at each diameter.

Main factors that influence flow rate through a venous bypass graft are its diameter and length. It is by increasing the flow rate through the bypass graft that AVF has its beneficial effect. Previous studies in our laboratory showed that increasing flow resulted in decreased platelet and decreased fibrin deposition in prosthetic grafts placed in the venous system.[24] It has also been demonstrated that higher flow is associated with improved patency after venous reconstructions.[1-7,9-17]

Several authors have suggested the use of an AVF only as a temporary adjunct to venous reconstructions.[3,6,9-14,27] Others reported graft occlusion after takedown of the AVF.[3,4,24] It would be ideal if the benefit of AVF could be maximized while any harmful consequences were controlled.

Our in vitro model confirmed our hypothesis that although a larger fistula results in increased flow in the

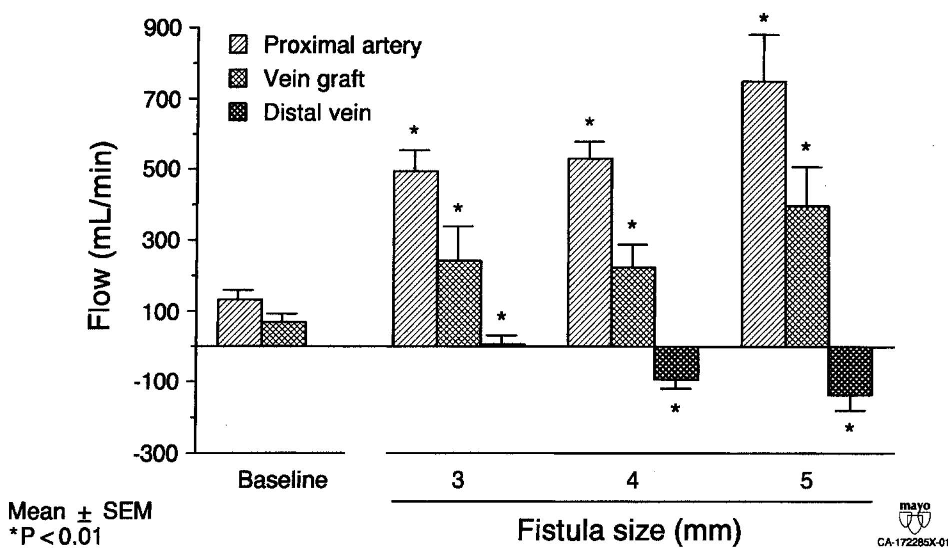

Fig. 6. Canine model. Mean arterial and venous flow after femorocaval bypass procedure and AVF.

proximal vein, it also increases significantly the distal venous pressure. The larger the fistula, the less is the venous outflow from the extremity. Using a 5-mm AVF in the in vitro model, venous return was completely interrupted.

The canine model demonstrated that after a bypass procedure is performed on an occluded iliofemoral venous system the venous pressure in the limb was dependent on the size of the fistula. With a fistula-to-graft ratio of 0.375, distal femoral venous pressure was reduced and was near normal. It did not decrease compared with preoperative values, with a fistula-to-graft ratio of 0.5 or higher.

Exercise had beneficial effect on the limb hemodynamics. After electrical stimulation, a significant increase in venous return was noted in group 1 (fistula diameter, 3 mm), from 7 ml/min to 67 ml/min. No significant increase in distal venous return could be demonstrated, however, in groups 2 and 3 with exercise. There was increase in flow in the distal artery; however, it was not statistically significant. There was decrease in proximal artery flow. The mechanism of this change in the flow pattern is not clear, but it appears to be a result of decreased flow through the AVF during exercise. We observed high venous pressures in the limb during muscle contractions. We also hypothesize that venous compliance in the limb decreases during and after exercise, resulting in higher venous return. These changes in the local hemodynamics result in decreased flow through the AVF. However, these changes are not observed in the presence of a large AVF because the higher flow through fistula overcomes these compliance changes.

We were unable to evaluate the hemodynamic changes at 2 weeks in this model because of the high occlusion rate of our grafts. Autopsy evaluation revealed thrombus in the vein, in most cases extending from the fistula to the inguinal ligament where the graft had been externally compressed between scar and the inguinal ligament. It is apparent from this study that the model is not adequate to evaluate long-term results in venous reconstruction.

We conclude that flow can be increased in a venous graft or thrombectomized vein with the use of an AVF. The price that must be paid, however, is the increase in distal venous pressure and the potential decrease of venous outflow from the impaired extremity. If venous outflow obstruction is treated with reconstruction, a fistula-to-graft ratio of 0.375 will increase flow through the graft and still allow orthograde flow in the distal vein with decreased pressures compared with preoperative values. Exercise promotes orthograde flow in the presence of such an AVF.

Our current recommendations on the construction of an AVF at the groin in patients who undergo femorofemoral or prosthetic FCG procedures are the following. For a 10-mm graft, a 3-mm to 4-mm fistula should be used to maintain a favorable graft-to-fistula ratio. If pressure measurements in the vein show increased values compared with the pressures from before reconstruction, the fistula should be further narrowed to decrease flow. Similarly, if an intraoperative duplex scan confirms flow reversal in the vein distal to the fistula, the size of the fistula should be decreased. If possible, fistulas in our patients are maintained while the bypass grafts are patent to provide the maximal benefit.

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